CM18 Ecloud/TMCI Feedback

Progress and future directions

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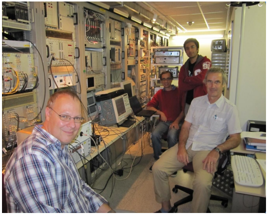
SPS Ecloud/TMCI Instability R&D Effort

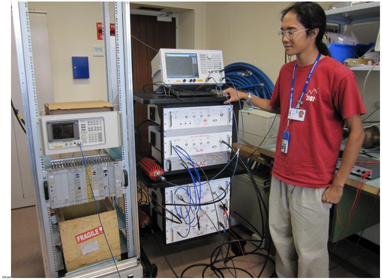
- Motivation - control Ecloud and TMCI effects in SPS and LHC via GHz bandwidth feedback
- Ongoing project SLAC/LBL/CERN via US LARP
- Proton Machines, Ecloud driven instability - impacts SPS as high-current LHC injector
  - Photoelectrons from synchrotron radiation - attracted to positive beam
  - Single bunch effect - head-tail (two stream) instability
- TMCI - Instability from degenerate transverse mode coupling - may impact high current SPS role as LHC injector
- Multi-lab effort - coordination on
  - Non-linear Simulation codes (LBL - CERN - SLAC)
  - Dynamics models/feedback models (SLAC - LBL-CERN-Stanford STAR lab)
  - Machine measurements- SPS MD (CERN - SLAC - LBL)
  - Kicker models and simulations (LNF-INFN,LBL, SLAC)
  - Hardware technology development (SLAC,)

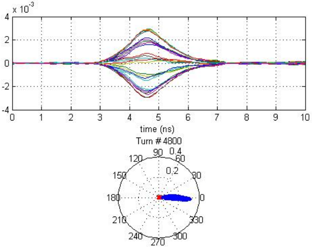
Organization and People - Some welcome new faces

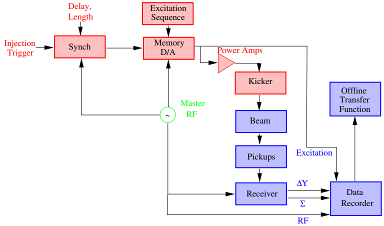
- SLAC J. Fox (50%), K. Li, C. Rivetta(50%), J. Olsen, J. Dusatko(30%), M. Pivi(20%)
- J. Cesaratto (Toohig Fellow)
- Ozhan Turgut, K. Pollock (Stanford Graduate Students)
- CERN - W. Hoefle, B. Salvant, U. Wehrle
  - SPS/LHC Transverse Feedback
  - MD planning and MD measurements
  - TMCI simulations and measurements
- LBL J-L Vay, M. Furman, Z. Paret R. Secondo, S. De Santis
  - Kicker study, Ecloud Simulation effort (WARP), Pickup Equalizer
- LNF-INFN F. Marcellini, S. Gallo, M. Zobov, A. Drago
  - Kicker study, Impedance estimates

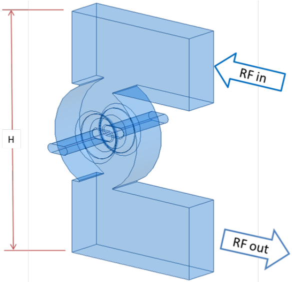


Recent efforts and Recent progress



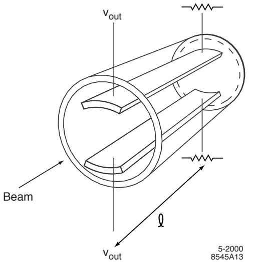


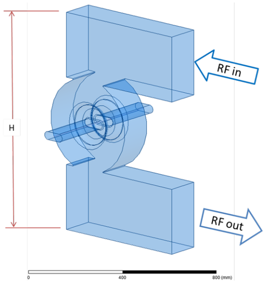


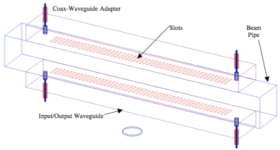


Kicker Options Design Study

- LNF-INFN,LBL and SLAC Collaboration. Excellent progress 2012
- Goals - evaluate 3 possible options
  - Stripline (Arrays? Tapered? Staggered in Frequency?)
  - Overdamped Cavity (transverse mode)
  - Slot and meander line (similar to stochastic coooling kickers)
- Based on requirements from feedback simulations, shunt impedance, overall complexity - select path for fab



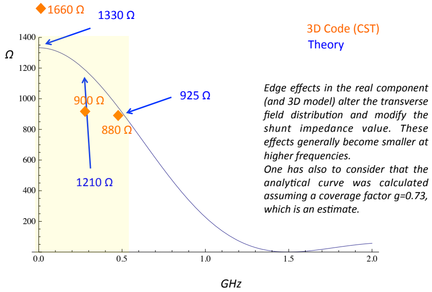




Kicker Options - Ideas from S. De Santis and Z. Paret

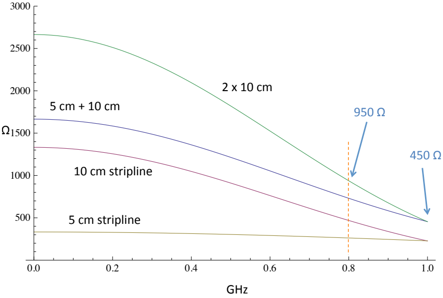
- Study of multiple striplines for bandwidth and overall shunt impedance
- RF models and estimates

10-cm Stripline



S. De Santis April 18, 2012

Two Striplines (10 and 5 cm)

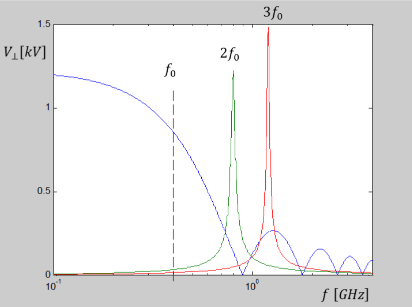


S. De Santis April 18, 2012

Kicker Options - Idea from S. Gallo

- Use 25 ns interval between bunches, have kicker with 20 ns fill time
- High shunt impedance, requires more complex off-diagonal processing, input and output data at different rates

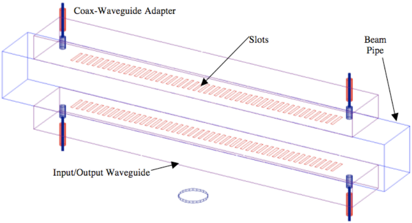
	Kicker #1	Kicker #2	Kicker #3
Type	Stripline	Cavity, TM110 defl. mode	Cavity, TM110 defl. mode
3-dB bandwidth	DC – 400 MHz	800 ± 16 MHz	1200 ± 16 MHz
Length	17 cm	15 cm	10 cm
Filling time	0.6 ns	10 ns	10 ns
Q_l	---	25	38
Shunt Impedance	≈ 1.5 kΩ (@ DC)	≈ 1.5 kΩ (@ 800 MHz)	≈ 2.2 kΩ (@ 1200 MHz)

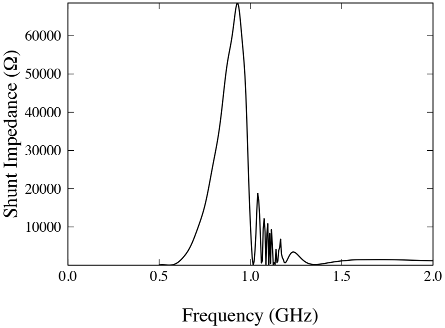


Assuming that each kicker is powered by a 1 kW source covering the entire device bandwidth, the resulting transverse voltage transferred to the beam as a function of the frequency is shown in the following plot.

Kicker Options - Idea from J. Cesaratto

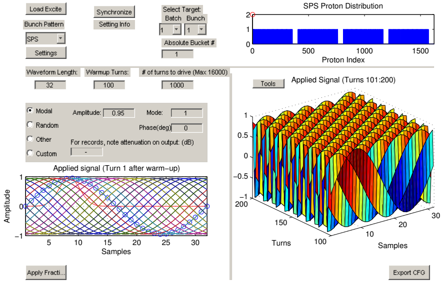
- similar to stochastic cooling kickers
- wideband - (longitudinal Impedance estimate in progress by M. Zobov)



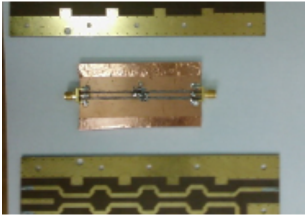


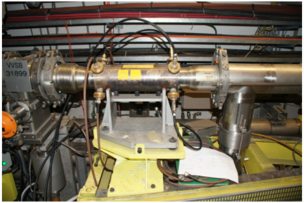
System Development for MD studies

- 4 GS/sec bunch-synchronized random excitation system with GUI
- Broadband 80W 20 - 1000 MHz amplifiers
  - Not ideal, useful for MD studies
  - Chassis , couplers, remote control for tunnel hardware
- Hardware equalizer for real-time front end



Hardware Equalizer





- Pickup response distorts beam signals
- Long cables also have nonlinear phase response
- Existing software equalizer used in matlab data processing
- we need a real-time (hardware) equalizer for processing channel
- Started by R. Secondo, now K. Pollock

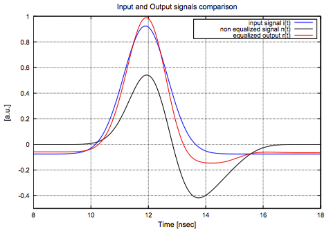
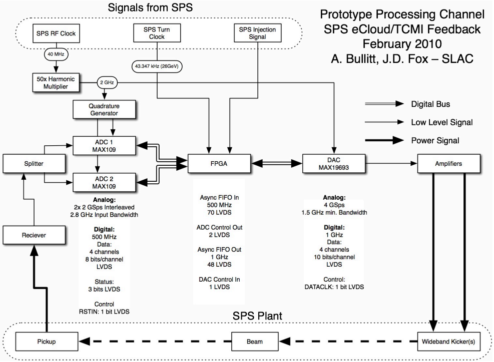


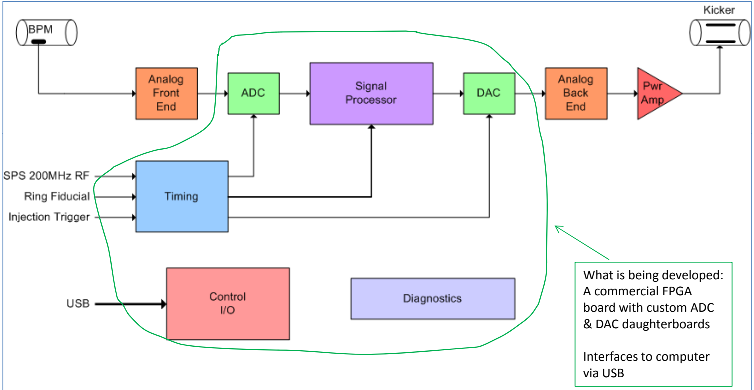
Figure 8: The input signal $i(t)$, non-equalized signal $n(t)$ and equalized output $r(t)$ using in the model a polynomial $P(s)$ with the values reported in Table 1.

4 Gs/sec. 1 stack SPS feedback channel



- We are building a proof-of-principle channel for closed loop tests in SPS before the 2013 shutdown, using existing kicker and excitation system
- Flexible reconfigurable processing - evaluate multiple processing algorithms

Proof of Principle processing

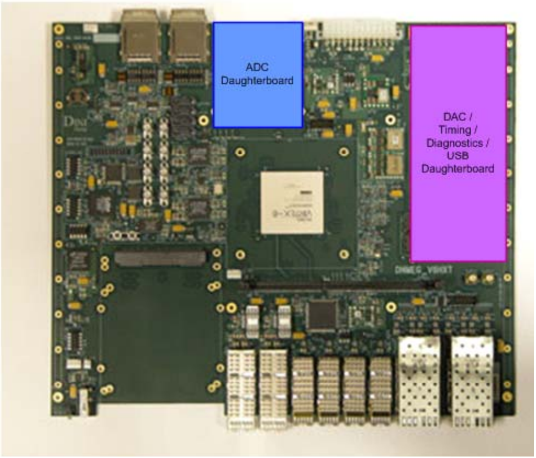


SPS Bunch Slice Feedback Demo System – Block Diagram

Prototype using FPGA evaluation board

Implementation Details:

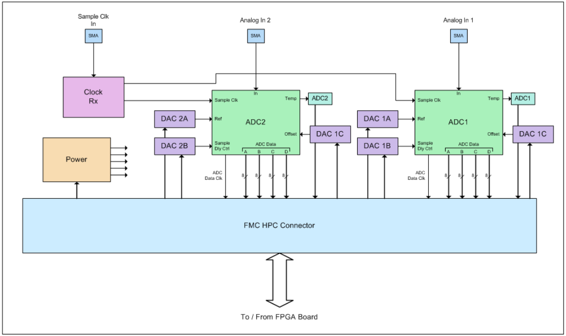
- Developing Two Daughterboards: DAC Board & ADC Board
- DAC board also contains circuitry for Timing, Diagnostics and USB interface
- This flavor of FPGA is optimized for high-speed serial I/O, but still contains enough DSP resources (864 slices) for our requirements
- Has up to 16GB of DDR3 memory
- Has two high-speed I/O connectors for fitting daughterboards onto

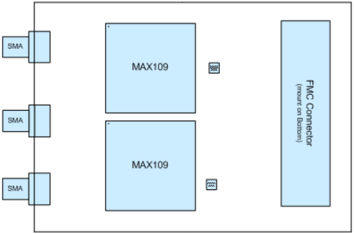


4 GS/sec ADC daughtercard

ADC Daughterboard:

- Uses two Maxim MAX109 2.2GSa/s 8-bit ADCs in interleaved mode to get 4GSa/s sampling
- Receives external sample clock
- Delay for interleaved samples is generated externally
- Has fine delay vernier control for sample aperture (32ps max)
- Adjustable reference level
- Adjustable input offset compensation

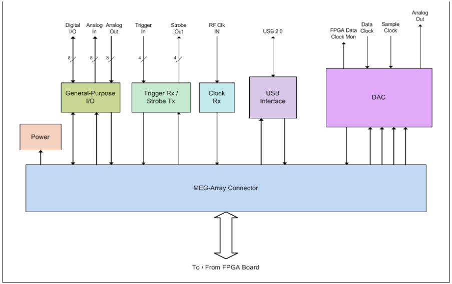


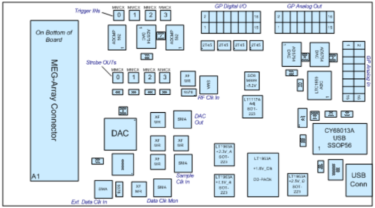


4 GS/sec D/A daughtercard with synchronization and timing functions

DAC Daughterboard:

- Uses Maxim MAX19693 12-bit 4 GSa/s DAC
- Rx's External 2GHz sample clock
- Also Rx's RF clock and External Data Clocks
- Has output monitor for FPGA data clock
- DAC board also contains circuitry for Timing, Diagnostics and USB interface:
  - USB 2.0 Interface
  - (4) High-Speed Trigger Inputs
  - (4) High Speed Strobe Outputs
  - (8) General-Purpose Digital I/O
  - (4) Slow ADC Channels
  - (4) Slow DAC Channels

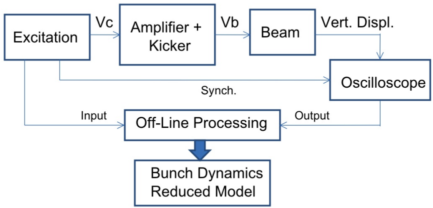




Driven Beam Motion MD Experiments July/August, November 2011 and April 2012

Goal: Drive individual sections of the bunch - Estimate Models

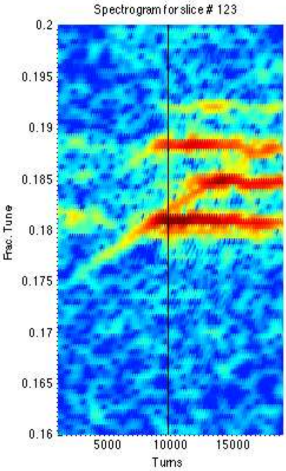
- Excitation - Power Stage - Vertical displacement measurement.
- Estimate bunch reduced dynamical model in open loop- Below e-cloud instability threshold. Increase currents and study dynamics change
- Compare MD results to macro-particle simulation codes

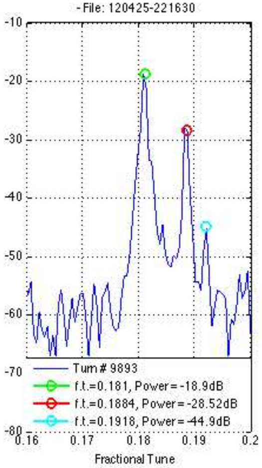


- Drive individually different areas of the bunch (Excitation - Amplifier - Kicker)
- Measure with scope the receiver signals $\Delta - \Sigma$. Estimate vertical displacement for different sections of the bunch.
- Based on Input-Output signals, estimate bunch reduced model.

Excitation MD July/August, Nov 2011 and April 2012

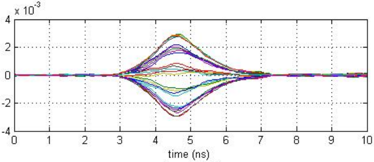
- Significant developments and sophisticated analysis
  - Excitation methods (chirps, random, selected modes)
  - ability to clearly excite through mode 4

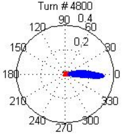


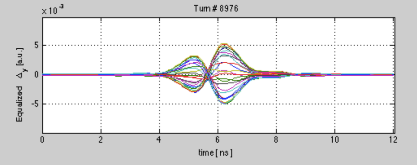


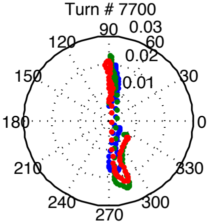
Vector (Modal) Analysis of Beam Motion J. Cesaratto

- We excite the beam from our amplifier array
- Study motion via pickup array, receiver system, digitize at 40 GS/sec.
- Plot slice phase at modal frequency





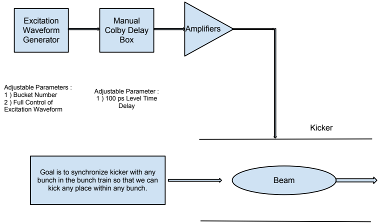


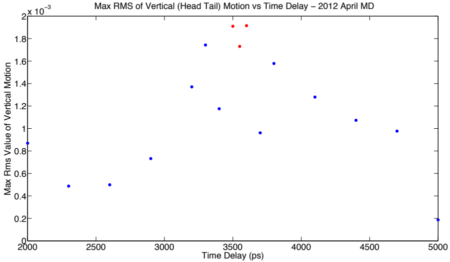


Barycentric mode 0 motion

Progress - Techniques to time a selected bunch and position (O. Turgut)

- We excite the beam from our amplifier array
- To control the modes excited, we must have precision in excitation timing
- an off-time Mode 0 excitation will excite mode -1, 1
  - methods to repeatably position the kick, time the system
  - methods to maximize the effective kick applied to the beam



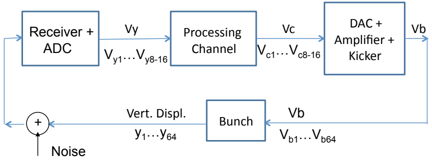


Barycentric driven motion

Progress in Simulation Models

- Significant efforts, including feedback to WARP, Head-Tail and CMAD
- Significant progress, especially in understanding numeric noise in models, impact on feedback noise model
- Still needs realistic channel noise study, sets power amp requirements
- Still needs more quantitative study of kicker bandwidth requirements
- Head-tail offers path to evaluate TMCI and feedback methods
- Critical to validate simulations against MD data
- Continued progress on linear system estimation methods

Add realistic components to the feedback channel - CMAD / HeadTail / Warp



- Bunch is sampled in z using 64-80 samples (equal charge - equal distance)
- Receiver, processing channel, amplifier, kicker include frequency response, signal limits and noise.
- Processing channel can operate from 1 to 64 samples to model different sampling rates.

CM18 Ecloud/TMCI Progress

- Kicker design/estimation effort
  - Significant progress, welcome contributions from LBL, LNF-INFN and SLAC.
  - Important Milestone - recommendation of geometry for CERN fab, SPS installation
- Continued development SPS 4 GS/sec. vertical excitation system
  - System with 4 85W 20-1000 MHz amplifier array, excitation system
  - Used for MD measurements Summer 2011, Nov 2011, April 2012
  - Increasingly sophisticated analysis codes
  - Results show ability to excite through mode 4, value of beam diagnostic tool
- Understand Ecloud/TMCI dynamics via MD data, reduced models and numeric simulations
  - Extraction of system dynamics, development of reduced (linear) coupled-oscillator model for feedback design estimation
  - Inclusion of feedback models in WARP, CMAD and Head-Tail codes
- Design progress - 4 GS/sec processing demonstration prototype
  - FPGA platform, with D/A and A/D daughtercards in fab
  - Builds on existing timing and amplifier system for proof of principle tests

Research Goals 2012 and Beyond

- Technology R&D - specification of wideband feedback technical components
- Technical Analysis of options, specification of control requirements
  - Single bunch control (wideband, vertical plane) - Required bandwidth?
  - Control Algorithm - complexity? Flexibility? Machine diagnostic techniques?
  - Fundamental R&D in kickers, pickups - technology demonstration in SPS
- Develop proof of principle processing system, evaluate with machine requirements
- System Design proposal and technical implementation/construction plan
- Plans 2012-2013
  - Develop a technology small-scale prototype, develop wideband kicker
  - Functionality to test feedback techniques on a subset of bunches, evaluate options
  - Excellent Ph.D. material (accelerator physics, nonlinear control), can support several students
- We will learn from a limited "quick prototype" at the SPS
- Can then confidently design a true operational system for SPS,

- J. Cesaratto, et al *Excitation of Intra-bunch Vertical Motion in the SPS - Implications for Feedback Control of Ecloud and TMCI Instabilities* Proceedings IPAC12
- S. De Santis, et al *Study of a Wideband Feedback Kicker for the SPS* Proceedings IPAC12
- M. Venturini, et al *Analysis of Numerical Noise in Particle-In-Cell Simulations of Single-Bunch Transverse Instabilities and Feedback in the CERN SPS* Proceedings IPAC12
- C. Rivetta, et al*Feedback System Design Techniques for Control of Intra-bunch Instabilities at the SPS* Proceedings IPAC12
- C. Rivetta, et al *Reduced Mathematical Model of Transverse Intra-bunch Dynamics* Proceedings IPAC12
- J. Fox et al *A 4 GS/s Synchronized Vertical Excitation System for SPS Studies - Steps Toward Wideband Feedback* Proceedings IPAC12
- M. Pivi, et al *Simulation Code Implementation to Include Models of a Novel Single-bunch Instability Feedback System and Intra-beam Scattering* Proceedings IPAC12
- T. Mastorides, et al, *Radio frequency noise effects on the CERN Large Hadron Collider beam diffusion*, PRST-AB 14,092802 (2011)
- T. Mastorides, et al, *Studies of RF Induced Bunch Lengthening at the LHC*, Proceedings PAC 11, NY
- T. Mastorides, et al, *RF system models for the CERN Large Hadron Collider with application to longitudinal dynamics*, PRST-AB 13:102801,2010

- C. Rivetta, et al, *Mathematical Models of Feedback Systems for Control of Intra-bunch Instabilities Driven by Eclouds and TMCI*, Proceedings PAC 2011, New York
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- J-L Vay, et al, *Direct Numerical Modeling of E-cloud Driven Instability of a Bunch Train in the CERN SPS*, Proceedings PAC 2011, New York
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- J-L Vay, et al, *Numerical modeling of E-cloud Driven Instability and its Mitigation using a simulated Feedback system in the cERN SPS*, Presented at the Ecloud 2010 ICFA Workshop, Ithaca, NY
- R. Secondo, et al, *Simulated Performance of an FIR-based Feedback System to Control Electron Cloud Single-Bunch Transverse Instabilities in the CERN SPS*, Presented at the Ecloud 2010 ICFA Workshop, Ithaca, NY
- D. Van Winkle, et. al., *Commissioning of the LHC Low Level RF System Remote Configuration Tools* Presented at IPAC'10, Kyoto, Japan, 23-28 May 2010, pp TUPEA063

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- J.-L. Vay et. al., *Simulation of E-cloud Driven Instability and its Attenuation Using a Feedback System in the CERN SPS*, Proceedings IPAC 2010, 23-28 May 2010, Kyoto, Japan.
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- J.D. Fox, et. al., *Feedback Techniques and Ecloud Instabilities - Design Estimates*, SLAC-PUB-13634, May 18, 2009. 4pp. Presented at Particle Accelerator Conference (PAC 09), Vancouver, BC, Canada, 4-8 May 2009.
- J. R. Thompson et. al., *Initial Results of Simulation of a Damping System of Electron Cloud-Driven Instabilities in the CERN SPS*, Presented at Particle Accelerator Conference (PAC 09), Vancouver, BC, Canada, 4-8 May 2009.
- Performance of Exponential Coupler in the SPS with LHC Type Beam for Transverse Broadband Instability Analysis 1 R. de Maria BNL, Upton, Long Island, New York, J. D. Fox SLAC, Menlo Park, California, W. Hofle, G. Kotzian, G. Rumolo, B. Salvant, U. Wehrle CERN, Geneva Presented at DIPAC 09 May 2009
- WEBEX Ecloud Feedback mini-workshop August 2009 (joint with SLAC, CERN, BNL, LBL and Cornell).
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W. Hofle, *E-cloud feedback activities for the SPS and LHC*, CERN Electron Cloud Mitigation Workshop 08.

R. De Maria, *Observations of SPS e-cloud instability with exponential pickup*, CERN Electron Cloud Mitigation Workshop 08.

G. Rumolo, *Experiments on SPS e-cloud instability*, CERN Electron Cloud Mitigation Workshop 08.

M. Venturini, *Progress on WARP and code benchmarking*, CERN Electron Cloud Mitigation Workshop 08.

SPS Studies 2009, 2010, 2011

- Open-Loop unstable beam measurements
- Vertical Instability develops within 100 turns. Time domain ,frequency domain studies 1E11 p/bunch
- Use this technique to compare models, MD data - extract beam dynamics necessary to design feedback. Roughly 25 slices (250 ps) between displacement maxima and minima
- Spring/summer 2010 - develop 4 Gs/sec. excitation system, drive tapered pickup as kicker
    - pickups and receiver studies
    - Noise, transverse resolution
    - 25 microns rms at 0.5E11 (vertical)
- Beam Excitation studies, stable beam
    - Develop excitation system with synchronized oscillators
    - Use 20 - 1000 MHz amplifier array, with 200 MHz bandwidth kicker
    - Study internal modes, look for dynamics change as currents